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Sodium Displacement in Saline Soils Measured by a Non-destructive Method

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ABSTRACT. Leaching of sodium was investigated in columns of loam and clay saline soils in relation to different methods and initial water content. Non-destructive measurement for the distribution of the applied radiosodium was made during the leaching course by gamma spectrometry. The results indicated that the method of leaching appeared the most important factor in altering the Na distribution. Based on the magnitude of the Na peak displacement with respect to water applied, the efficiency of methods in leaching of the loam soil followed the order: simulated rain (SR) > continuous ponding (CP) > intermittent ponding (IP) at air dry and CP > SR > IP at both field capacity and near saturation initial water content. The results were reversed in the clay soil.

Pre-wetting the loam soil slowed down the movement of sodium. In the clay soil, no consistent effect on Na movement occurred with increasing initial water content. The efficiency in displacement was explained on the basis of the effective fraction of water participating in solute transport.

Among the many factors influencing solute transport in soil, the initial water content, water velocity, method of water application, and degree of solute reaction with the soil are particularly important (*e.g.*, Dahiya *et al.* 1980, Ghuman *et al.* 1975, Bolt 1978, Oster *et al.* 1972). The influence of the first three factors are still controversial (*e.g.*, Kirda *et al.* 1973, Ghuman and Prihar 1980). Further, the influence of a combination of these factors on solute movement has not been examined.

For most studies, chloride was used to determine the leaching of salts. However, little has been done on the leaching of sodium under conditions associated with the leaching of saline soils.

In the present investigation, the effects on sodium displacement in saline soils the method of leaching, the initial water content, and soil texture were considered jointly. Distribution of surface-applied ^{22}Na in soil columns was determined non-destructively and instantaneously by means of gamma spectrometry.

Materials and Methods

Calcareous alluvial soils with no B horizon were used. The site from which the soils were taken had not been cultivated for several years and is located 25 km south of Baghdad, Iraq. The groundwater depth fluctuated from 80 to 120 cm and resulted in salinization of the soil. Two contrasting soil textures (loam and clay) were sampled from the upper 0-30 cm depth. Further characteristics of the soils are given in (Table 1). Procedures given in Black *et al.* 1965 were used for measuring soil characteristics. Particle size distribution was measured by the hydrometer method and elemental concentrations by atomic absorption spectrometry (Perkin Elmer 305 B).

The soils were screened through 1.00 mm sieve and uniformly packed in plexiglass columns (30 cm long and 5.4 cm inner diameter) to 20 cm depth. The bulk densities were 1.41 and 1.15 Mg m^{-3} for the loam and clay soils, respectively.

Table 1. Some physical and chemical characteristics of the soils used

Character	Loam^{+}	Clay^{+}
Clay (%)	24.0	47.0
Silt (%)	42.0	33.6
Sand (%)	34.0	19.4
Electrical conductivity (ds/m)$^{++}$	50.0	167.5
pH	7.83	7.02
Cation exchange capacity (cmol/kg)	21.6	28.4
Organic matter (%)	0.74	0.78
Lime (%)	25.2	27.1
Soluble cations (mg/kg)		
Ca	973	4931
Mg	766	1441
Na	1300	3685
K	129	188

\+ USDA textural class.

\++ Measured in extract of saturated soil paste.

Carrier-free NaCl solution containing 1.48 MBq (40 μCi) ^{22}Na in 5 ml was evenly distributed on the surface of each soil column. The soil columns were air dry (O=0.03 in the loam and 0.06 m^3 m^{-3} in the clay), field capacity (O=0.35 in the loam and 0.38 m^3 m^{-3} in the clay), or near saturation (O=0.46 in the loam and 0.47 m^3 m^{-3} in the clay). In the near saturation treatment, one pore volume of water was added to each soil column. Three leaching regimes were imposed. They were simulated rain (supplied automatically), intermittent ponding (the same amount received by simulated rain applied weekly), and continuous ponding (Marriotte technique). The leaching water was a river water and contained 142, 120, 32, and 3 mg/L of Ca, Na, Mg, and K, respectively.

Measurement of ^{22}Na distributions in soil columns was made during leaching (for 5 to 55 days) using gamma spectrometry with a NaI(T1) detector. The detector was lead-shielded and collimated to receive a gamma beam 3.0 cm wide, 8.0 cm deep, and 0.5 cm high. The pulses generated were amplified and fed into a single channel analyzer which was adjusted to receive pulses corresponding to an energy peak of 1.28 Mev from ^{22}Na. The count rates were then recorded automatically on a teleprinter. Details of the technique are given elsewhere (Fahad 1987).

Results and Discussion

For the same amount of water applied and irrespective of leaching time, Na behaved differently depending on soil type, method of leaching, and initial water content (Fig. 1). The method of leaching appeared to be the most important factor in altering the Na distributions. Since the method of leaching would determine the pattern of water flow through soils (*e.g.*, Wood and Davidson 1975; Mustafa *et al.* 1983), it is therefore expected that the pattern of salt distribution is closely associated with the pattern of water flow. Further, no consistent effect of the leaching method in displacing Na was observed in the two soils with increased initial water content. The leaching by simulated rain (SR) of the dry loam soil resulted in the greatest displacement in terms of peak position and the area under the distribution curves (Fig. 1 and Table 2). However, continuous ponding (CP) displaced most Na at field capacity initial water content. This was not the case in the clay soil where greatest leaching was achieved by intermittent ponding (IP) (Fig. 1d-f).

Differences in the sodium remaining in the soil columns were very small when one pore volume (pv) of water was applied (Table 2). Slight displacement occurred only in the columns leached by IP. However, as leaching proceeded (application of 2 pv), a major displacement of Na was produced in the dry loam soil leached by SR. As similar, but smaller effect was obtained from leaching the clay soil by IP.

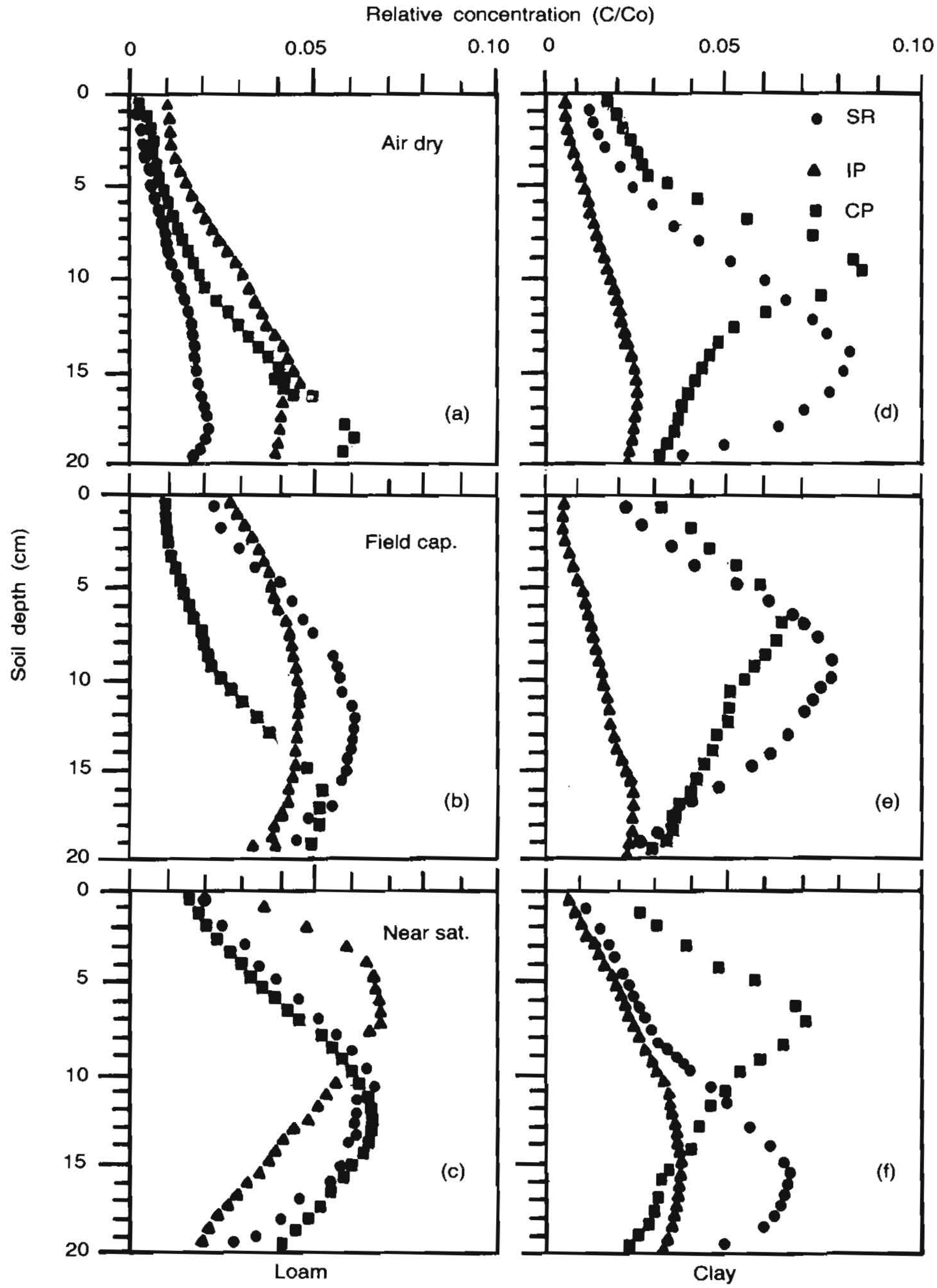

Fig. 1. Sodium concentration profiles in the loam and clay soils leached with two pore volumes of water by the three methods of leaching at three initial water contents (SR = simulated rain, IP = intermittent ponding, and CP = continuous ponding). (Co = initial concentration applied and C = measured concentration).

Table 2. Percent of ^{22}Na remaining in the soil columns leached with 1, 2, and 3 pore volumes (pv) of river water

Method of leaching+	Initial water status++	Percent of Na remained		
		1 pv	2 pv	3 pv
		Loam		
SR	AD	100.0	25.6	15.0
	FC	100.0	93.6	66.0
	NS	100.0	92.1	64.1
IP	AD	99.2	59.7	27.9
	FC	91.3	78.5	55.6
	NS	100.0	95.6	74.5
CP	AD	98.7	51.9	7.4
	FC	96.3	59.7	18.8
	NS	100.0	94.1	45.7
		Clay		
SR	AD	100.0	98.6	37.0
	FC	100.0	100.0	80.3
	NS	100.0	79.0	39.4
IP	AD	86.1	37.4	21.7*
	FC	90.7	32.5	16.5
	NS	97.0	53.3	31.9*
CP	AD	100.0	91.7	75.2
	FC	100.0	94.0	73.5
	NS	100.0	91.0	77.3

+ SR = simulated rain, IP = intermittent ponding, and CP = continuous ponding.
++ AD = air dry, FC = field capacity, and NS = near saturation.
* Percent remaining after 2.5 pv passed through.

For either soil and the same pore volumes of water passing through the soil columns, the differences in efficiency of the leaching methods may be explained on the basis of the effective volume of water participating in solute transport by convection and diffusion. During leaching of the loam soil, CP appeared as efficient in displacing Na as the SR and they were superior to the IP method. This was probably because the proportion of water applied continuously which passed large pores without displacing salts (*i.e.*, ineffective part) was very small. As similar effect on Na leaching by CP in undisturbed soil columns of low velocity flux was obtained by Fahad *et al.* (1988). In contrast, Kirda *et al.* (1973) and Dahiya *et al.* (1980) have shown greater displacements of Cl by water applied at a constant rate than when ponded.

Prolonged leaching (application of 3 pv) resulted in the displacement of most of the applied Na from the initially dry loam soil leached by SR and CP, and the clay soil initially at field capacity leached by IP (Table 2). In most cases, whether leaching was continuous or not, greater displacements occurred from initially dry soil. Also, differences in the Na remaining in the various soil columns were greater after the application of 3 pv of water.

Movements of sodium peak as a function of water applied are plotted in Fig. 2. Linear regression equations of the above data are given in (Table 3). The results obtained were consistent with the quantities of Na remaining unleached

Table 3. Regression equations of the Na peak advancement (cm) as a function of water applied (cm)

Method of leaching+	Initial water status++	Equations	Number of observation	Correlation coefficient
Loam				
SR	AD	y = 0.250 + 1.139 W	11	0.997**
	FC	y = −0.590 + 0.659 W	21	0.994**
	NS	y = −0.790 + 0.630 W	14	0.980**
IP	AD	y = 0.157 + 0.714 W	16	0.933**
	FC	y = −1.229 + 0.581 W	18	0.971**
	NS	y = −0.647 + 0.406 W	25	0.930**
CP	AD	y = 0.306 + 1.023 W	23	0.977**
	FC	y = −0.388 + 0.991 W	10	0.999**
	NS	y = −0.720 + 0.688 W	16	0.992**
Clay				
SR	AD	y = 0.672 + 0.753 W	17	0.994**
	FC	y = −0.196 + 0.599 W	20	0.999**
	NS	y = −0.658 + 0.917 W	16	0.997**
IP	AD	y = 0.299 + 0.744 W	17	0.936**
	FC	y = 0.661 + 1.430 W	10	0.992**
	NS	y = −1.149 + 0.890 W	17	0.985**
CP	AD	y = −0.160 + 0.436 W	13	0.997**
	FC	y = −1.295 + 0.581 W	13	0.991**
	NS	y = 1.154 + 0.457 W	11	0.994**

+ SR = simulated rain, IP = intermittent ponding, and CP = continuous ponding.
++ AD = air dry, FC = field capacity, and NS = near saturation.
** Significant at P = 0.01 level.

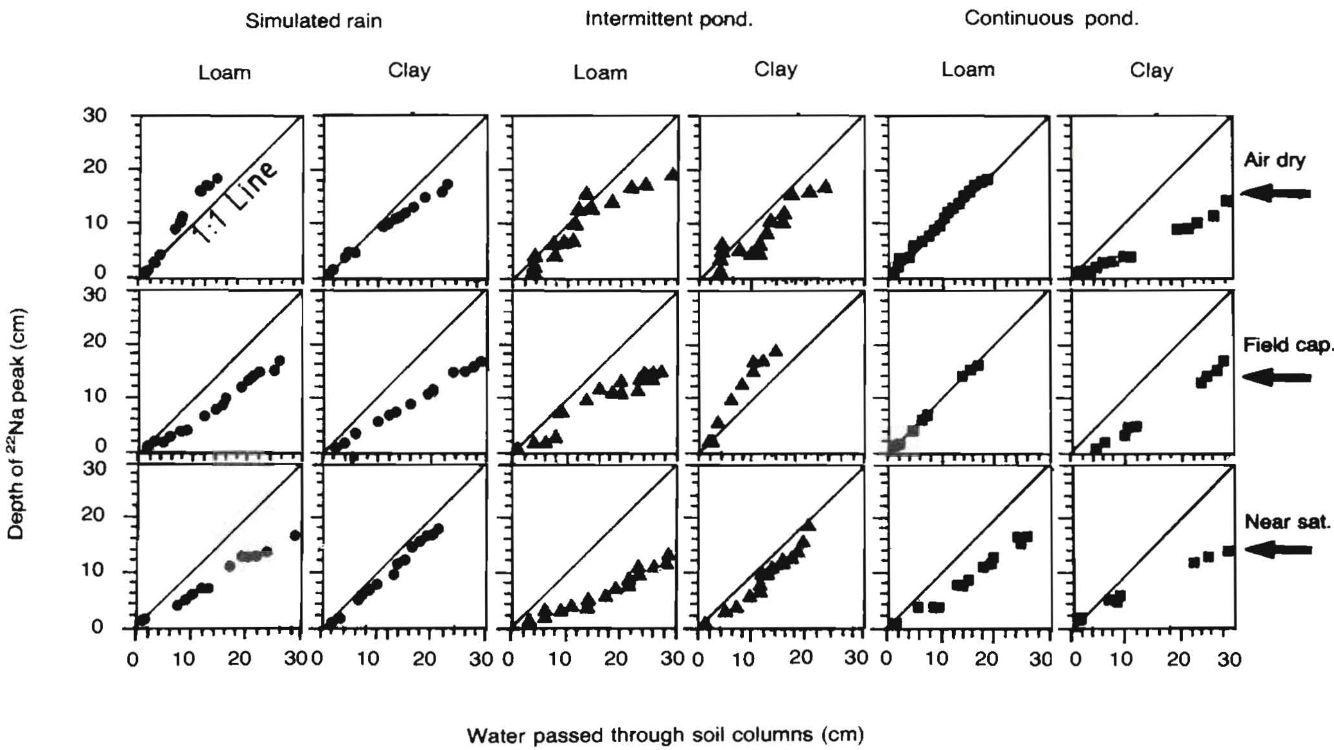

Fig. 2. Displacement of the sodium peak as a function of water applied in the soil columns leached by the three methods of leaching at the three initial water contents. (Regression equations are given in Table 3).

from the soil columns. Based on the coefficients (change in peak advancement per unit change in water passed through soil columns) of the equations, the efficiency of the leaching methods for the loam soil can be arranged in the following order: SR > CP > IP at air dry and CP > SR > IP at both field capacity and near saturation.

For the clay soil initially at field capacity, the IP method gave the highest coefficients and the CP method the lowest.

Table 4. Time required to move the Na peak to 20 cm depth. (Values are calculated based on regression equations of the Na peak advancement as function of time)

Method of leaching	Initial water status+	Time (day)
Loam		
Simulated Rain	AD	8.7
	FC	29.9
	NS	22.5
Intermittent Pond	AD	22.9
	FC	41.1
	NS	48.4
Continuous Pond	AD	1.0
	FC	2.2
	NS	4.7
Clay		
Simulated Rain	AD	11.8
	FC	28.9
	NS	24.3
Intermittent Pond	AD	28.7
	FC	20.9
	NS	42.9
Continuous Pond	AD	2.7
	FC	7.3
	NS	7.3

+ AD = air day, FC = field capacity, and NS = near saturation.

A possible explanation of the low leaching efficiency of the CP in the clay soil is the high water and cation exchange capacity of the soil. Because the immobile fraction of the soil solution (Van Genuchten and Wierenga 1976) in the clay soil was high, a small quantities of solution was released resulting in less displacement at high velocity flux. Smith *et al.* (1985) postulated that water flow through macropores which bypass the adsorptive or retentive capacities of the soil matrix is a common phenomenon. Moreover, the long duration of the leaching associated with the IP caused greater movement by diffusion between the immobile and mobile regions, and by diffusion and convection during redistribution.

Considering only the duration of leaching, CP displaced more Na compared with the other two methods. This was indicated by the rate of Na peak advancement and, hence, the total time required to displace the peaks to the bottom of the soil columns (Table 4).

Unlike some reports (Warrick *et al.* 1971; Kirda *et al.* 1973; Ghuman *et al.* 1975), the advancement of the Na peak was found to depend on initial water content of the soils. In all columns of the loam soil, pre-wetting the soil slowed down the movement of Na. Furthermore, there was a large and consistent effect on Na movement of increasing the initial water content. The large movement of Na in initially dry soils may be explained by the occurrence of piston-like displacement. This is in agreement with the finding of White *et al.* (1986) where greater quantities of weakly- and strongly-adsorbed herbicides were leached from dry than soil that had been pre-wetted. Also, Dahiya *et al.* (1980) observed greater leaching of Cl in initially dry sandy loam soil. This behavior was reversed in the dry sandy soil.

Conclusion

The method of leaching strongly influenced the displacement of Na. Nevertheless, marked differences in Na displacement were observed. These were due either to differences in initial water content or to soil texture. For a given soil, differences in Na remaining unleached or in Na peak displacement were attributed partly to the portion of water participating effectively in solute transport. These were associated with the method of leaching or with the initial water content.

Leaching of saline soils by continuous ponding appeared equally effective as the other two methods in such soils and in soils of similar properties. This was indicated by the comparable quantities of water required for salt displacement. However, the much less time required by continuous ponding in the leaching process is important aspect in reclamation of land in arid and semi-arid regions where potential evaporation is very high.

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ازاحة الصوديوم في ترب ملحية وقياسه بالطريقة غير الهدمية

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درس انغسال الصوديوم في أعمدة تـربتين ملحيتين طميية وطينيـة وعلاقتـه بطرق غسل مختلفة، ومحتوى ماء إبتدائي مختلف. استعملت الطريقة غير الهدمية لقياس توزيع الصوديوم المشع المضاف خلال الغسل بواسطة طيف أشعة جاما، دلت النتائج أن طريقة الغسل كانت العامل الأهم في تغيير توزيع الصوديوم.

استناداً إلى مقدار إزاحـة قمة تـركيز الصـوديوم بـالنسبة إلى المـاء المضاف، كانت كفاءة غسل التربة الطميية ضمن الترتيب التالي:
المطر الاصطناعي > الغمر المستمر > الغمر المتقطع عند التربة الجافة، والغمر المستمـر > المطر الاصـطناعي > الغمـر المتقطع عنـد رطـوبـة السعـة الحقليـة والقريب من التشبع، وقد إنعكست النتائج في التربة الطينية.

ان ترطيب التربة الطمييـة قد أبـطأ حركـة الصوديـوم. ومن جهة أخـرى لم يحصل تأثير متناسق على حركـة الصوديـوم في التربـة الطينيـة مع زيـادة المحتوى الابتدائي من الماء. أن كفاءة الازاحة قـد فسرت على أسـاس الجزء الفعـال من الماء الذي يساهم في نقل الملح.